Application of a Multi-Particle Correlation Method to detect Charge Asymmetry in 200 GeV Au+Au Collisions

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Plan of Talk

Introduction

Methodology

Application to data

Evaluation of signal

Outlook

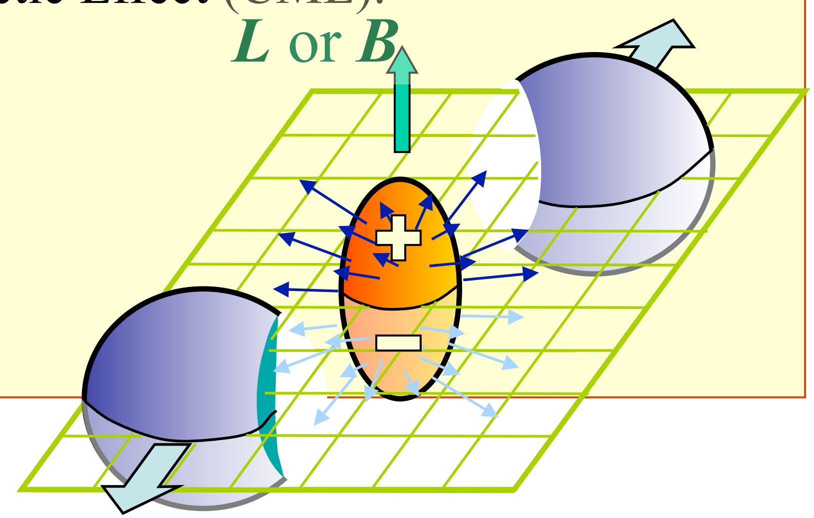
Summary

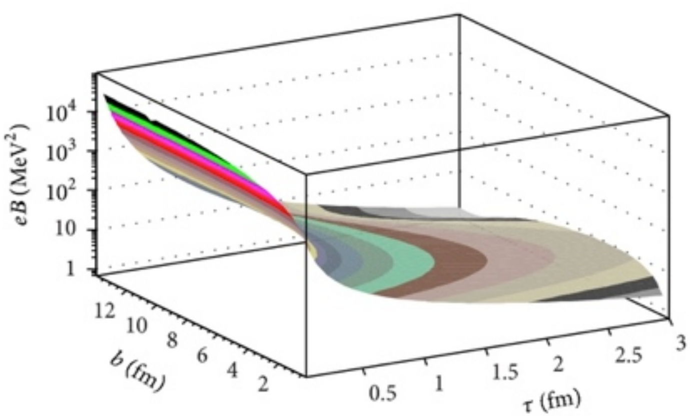
The CME effect

It has been proposed [1] that in heavy ion collisions, metastable domains may be created in which parity and CP symmetries are violated.

A combination of a net chirality of quarks within a domain and the extremely strong magnetic field in a heavy ion collision could lead to the manifestation of parity violation as a separation of charges along the angular momentum vector of the collision system [2] i.e. the Chiral Magnetic Effect (CME).

1.D. Kharzeev, R. D. Pisarski, and M. H. G. Tytgat, Phys. Rev. Lett. 81, 512 (1998).
2.D. Kharzeev and R. D. Pisarski, Phys. Rev. D 61, 111901 (2000).





Calculated Magnetic Field induced by spectators in 200 GeV Au+Au Collision strong at early (<2 fm) times

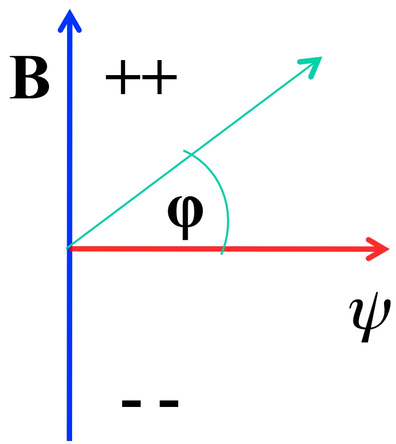
Y. Zhong et. al. Advances in High Energy Physics Volume 2014 (2014), Article ID 193039

Azimuthal distribution w.r.t the reaction plane ψ

$$N(\phi) = N_0(1 + \sum 2 v_n \cos(n\phi)) + 2a_1 \sin(\phi)$$

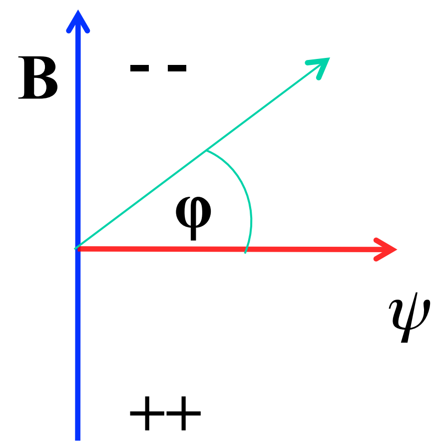
$\phi = \phi_{lab} - \psi$

$a_1>0$



Positive charges favor B

$a_1<0$

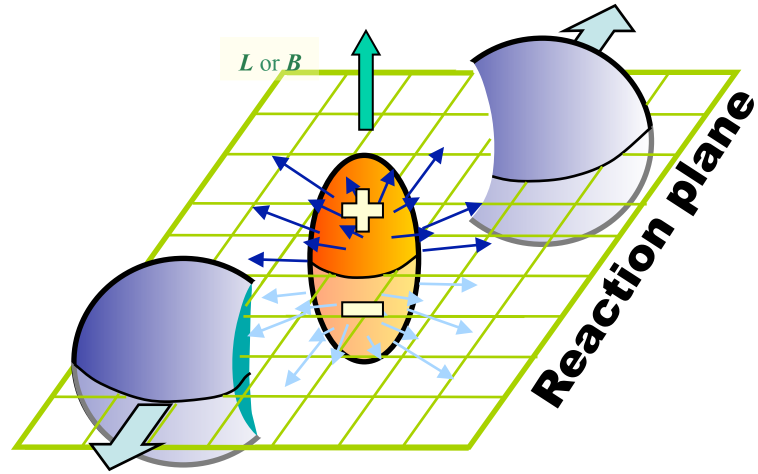


Negative charges favor B

Observation of a non-zero a_1 indicates charge separation along B field

Detection of azimuthal charge-asymmetry would provide strong evidence for the CME effect

Two-particle correlation Method

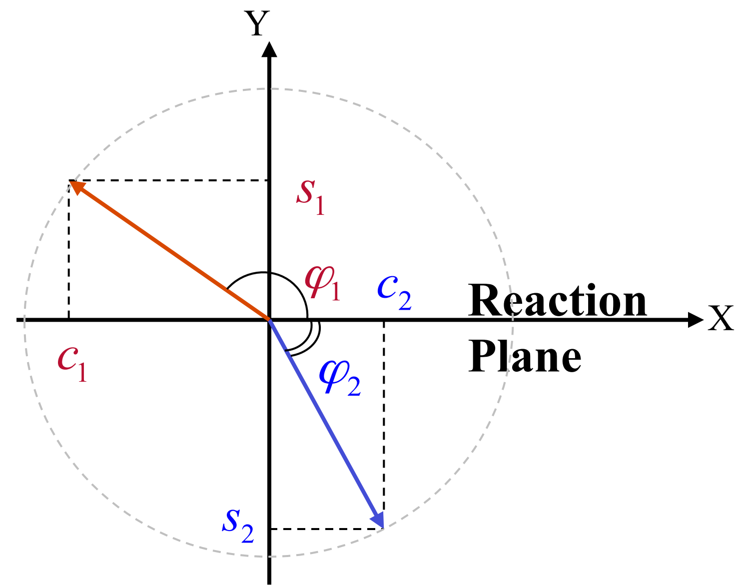


$$\frac{dN_\pm}{d\phi} \propto 1 + 2v_1\cos(\Delta\phi) + 2v_2\cos(2\Delta\phi) + \ldots + 2a_{1,\pm}\sin(\Delta\phi) + \ldots, \quad \Delta\phi = \phi - \Psi_{RP}$$

$$\langle\cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP})\rangle = \\ = \langle\cos\Delta\phi_\alpha \cos\Delta\phi_\beta\rangle - \langle\sin\Delta\phi_\alpha \sin\Delta\phi_\beta\rangle \\ = [\langle v_{1,\alpha}v_{1,\beta}\rangle + B^{in}] - [\langle a_\alpha a_\beta\rangle + B^{out}].$$

$\alpha, \beta = -, +$

$v_1 = 0$, $B^{in} \approx B^{out}$



$\Delta\phi_\alpha = \phi_1$ $\Delta\phi_\beta = \phi_2$

$C = < \cos(\Delta\phi_\alpha)\cos(\Delta\phi_\beta) >$

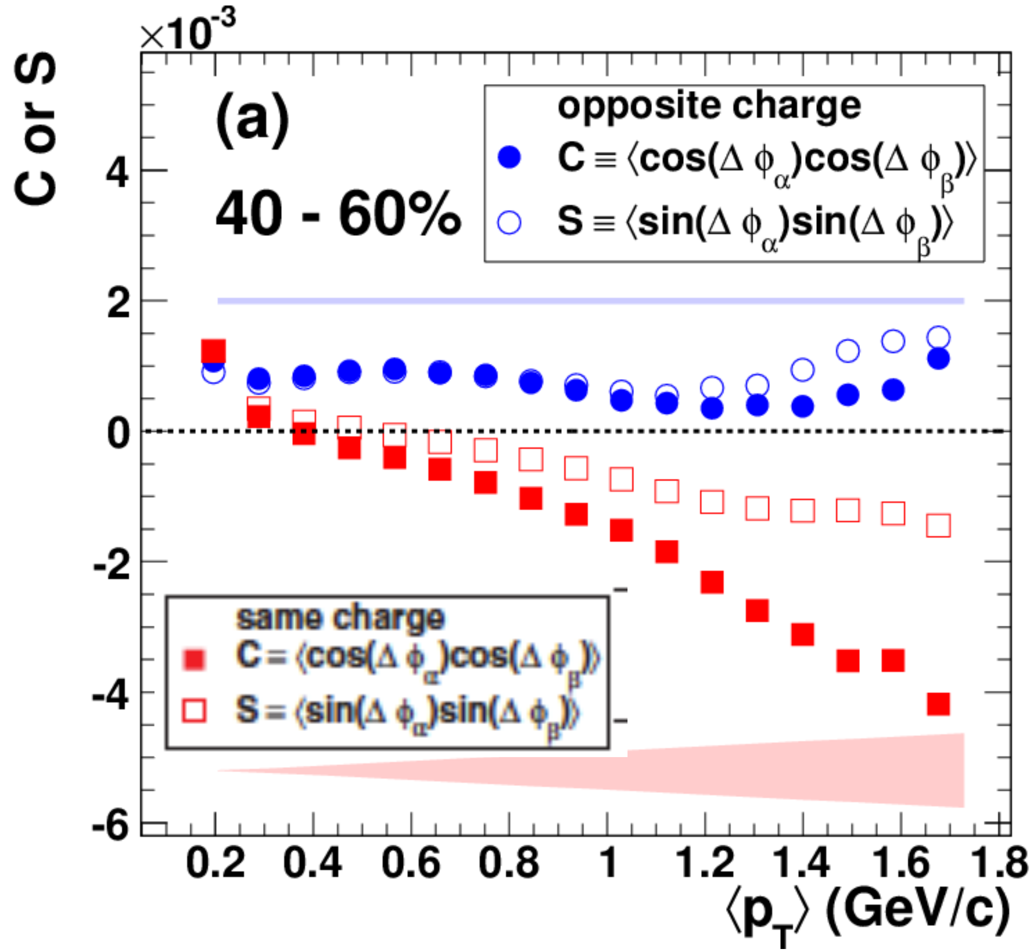
$S = < \sin(\Delta\phi_\alpha)\sin(\Delta\phi_\beta) >$

$a_\alpha a_\beta = S - C$

Signal proportional to square of a_1

Results from the two-particle correlation method applied to STAR data

Phys. Rev. C **88**, 064911,2013



For <p_T>=1.3 GeV/c for same charge pairs

C = -3.0e-03   S = -1.5e-03   S-C = 1.5e-03

a_1 = sqrt(S-C) ~ 4% Removing background calculated from same charge gives a1 ~ 2.5 %

The difference between same- and opposite-charge correlations are consistent with the expectations of the CME.

P-even local charge conservation coupled to elliptic flow modeled by charge balance functions has also been shown to generate same-charge three-point correlations comparable to the observed one.

There is a need for an independent method of assessing the LPV signal.

In the following we describe a multi-particle correlation method for obtaining the LPV signal and apply it to STAR data.

A multi-particle correlation method for the detection of charge asymmetry

Phys. Rev. C 83, 011901(R) (2011)

In brief :

a) Construct shuffled event from real event

b) Construct multi-particle correlators Cp and Cp_perp

c) Compare (Cp/Cp_perp)_sim with (Cp/Cp_perp)_data for different values of a_1

Construction of shuffled event from a real event

Event with p positively charged hadrons and n negatively charged hadrons

1	**2**	**3**	**4**	**5**	**6**	**7**	**----**	**p**	**p** positives
1	**2**	**3**	**4**	**5**	**6**	**7**	**----**	**n**	**n** negatives

Construction of charge shuffled event

1	**2**	**3**	**4**	**5**	**6**	**7**	**----**	**p**	**p** random choices
1	**2**	**3**	**4**	**5**	**6**	**7**	**----**	**n**	**n** remaining

All charge correlations are destroyed in the shuffled event

Construction of multi-particle correlators Cp and Cp_perp

Correlation variable $S = \sin(\phi_{lab} - \psi_2)$

Evaluate real event averages of S

$\langle S_p^{h+} \rangle$ = average S over the p positively charged hadrons in the event

$\langle S_n^{h-} \rangle$ = average S over the n negatively charged hadrons in the event

Evaluate shuffled event averages of S

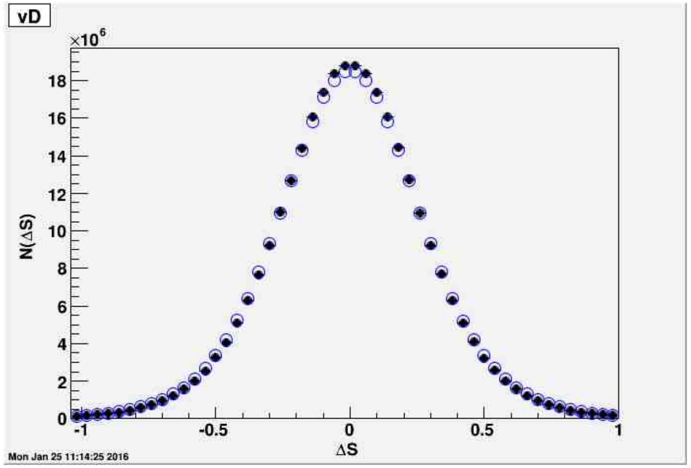
$\langle S_p^{h\mathrm{m}} \rangle$ = average over p randomly chosen hadrons in the same event

$\langle S_n^{h\mathrm{m}} \rangle$ = average over n remaining hadrons in the same event

Construction of multi-particle correlators Cp and Cp_perp

Real event (full symbols)
And shuffled event (open symbols)
distributions of <S>

Correlators reflect the difference
of these two distributions



The correlator **Cp** is the ratio of the real and shuffled event distributions

$$C_{\mathrm{p}}(\Delta S) = \frac{N\left(\left\langle S_p^{h+}\right\rangle - \left\langle S_n^{h-}\right\rangle\right)}{N\left(\left\langle S_p^{hm}\right\rangle - \left\langle S_n^{hm}\right\rangle\right)}, \quad \Delta S = \left\langle S_p\right\rangle - \left\langle S_n\right\rangle$$

The Multi-particle correlator **Cp_perp** is evaluated in the same way

with $S = \sin(\phi_{lab} - \psi_2)$ replaced by $S = \sin(\phi_{lab} - \psi_2 - \pi/2)$

Application of the method to data

a) Using particles with $0.2<p_T<1.0$ obtain v2 reaction planes Ψ_{2E} and ψ_{2W} from $0.5<\eta<1.0$ and $-1.0<\eta<-0.5$ respectively

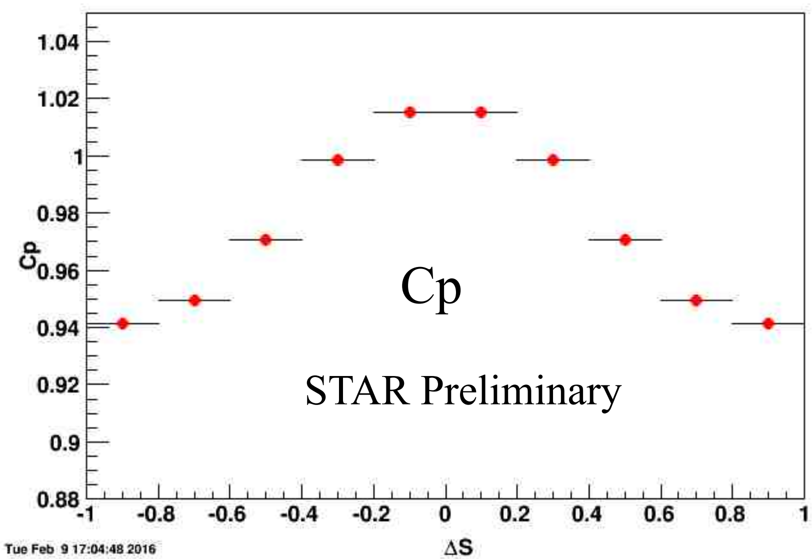
b) Construct Cp and Cp_{perp} for particles with $1.0<p_T<2.0$ taking care to use ψ_{2W} for $0.5<\eta<1.0$ and ψ_{2E} for $-1.0<\eta<-0.5$ to avoid non-flow effects

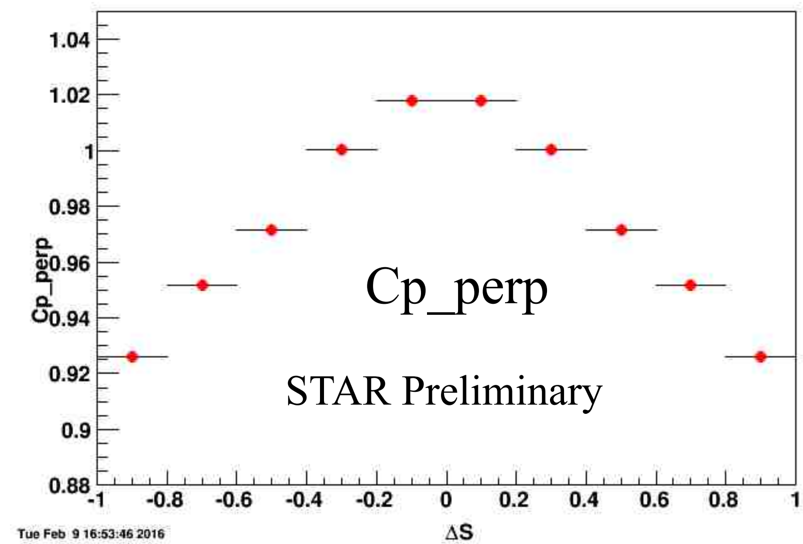
Results : Cp, Cp_perp, Cp/Cp_perp for data

200 GeV Au+Au

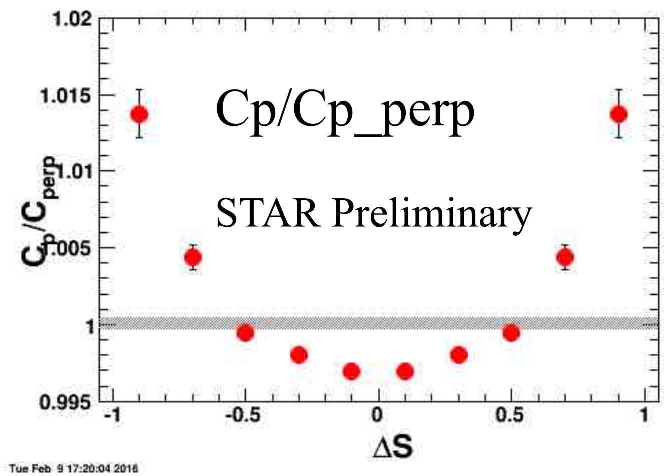
30%<cent<50% 1.0<pT<2.0

Note : Correlators obtained after reflecting all distributions about $\Delta S = 0$





Shape is concave which is evidence of a non zero charge asymmetry signal



Grey band is systematic error from dca and nhits variation

To evaluate the a1, the strength of the charge asymmetry term we turn to data driven simulations :

For each event lab azimuths of data particles are re-assigned using the function

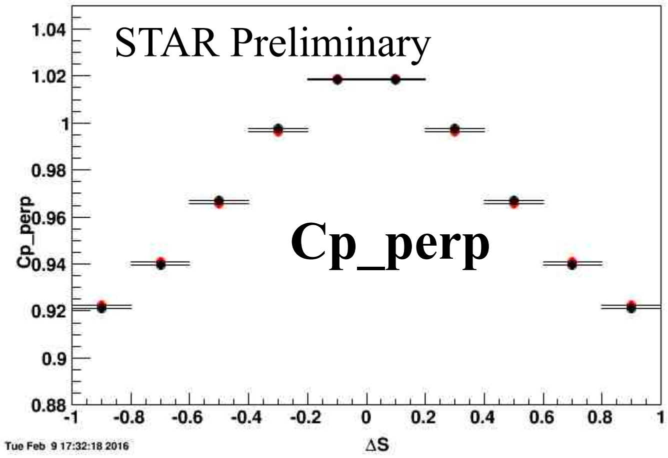
$$N(\phi_{lab}) = N_0(1+\sum_{1}^{4} 2v_n \cos(n(\phi_{lab}-\psi_n)) + 2a_1 \sin(\phi_{lab}-\psi_2))$$

Note : a_1 flips sign with charge, vn and ψn are as obtained from the data

A fraction of particles are chosen to decay (as lambdas and K0s) with their daughters receiving momentum boost. This ensures radial flow and local charge conservation effects and their dependence on the angle with respect to the reaction plane that are present in the data are also present in the simulation. Cp and Cp_perp are calculated for the simulated events.

Simulated events (contd)

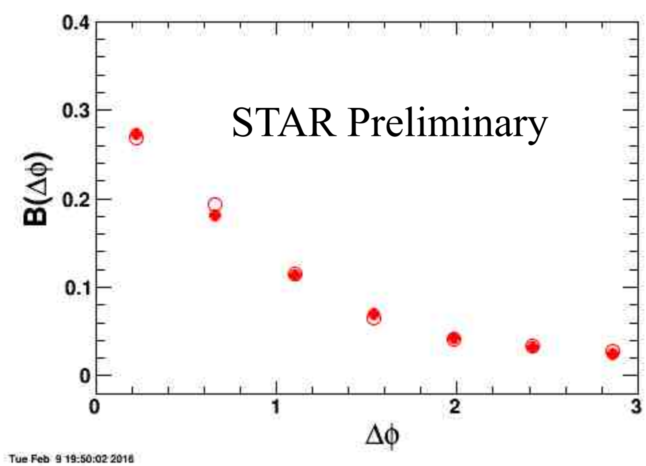
Finally the decay fraction is set by matching the Cp_perp of data :



Black symbols Sim

Red Symbols Data

Note : Correlator obtained after reflecting distributions about **ΔS = 0**

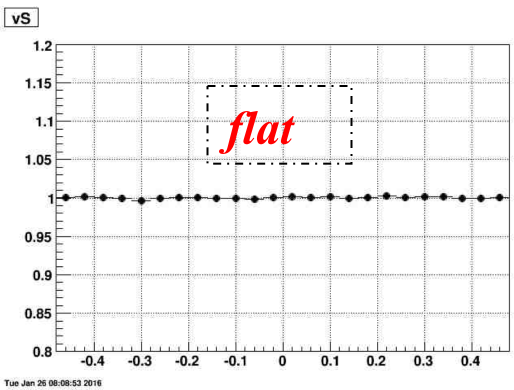


It is seen that the 0.2<p_T<2.0 GeV/c charge Balance Function for the sims (closed symbols) match those for the data (Open symbols)

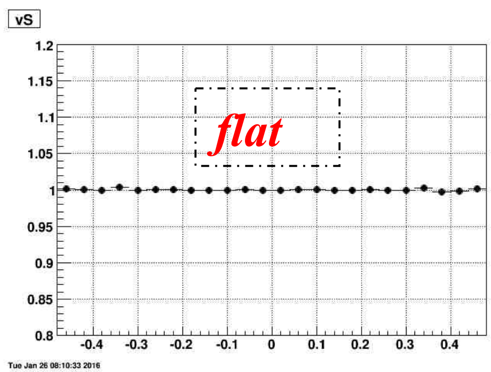
Shape response of correlators to physics

Simulation results with flow but no charge asymmetry or decay

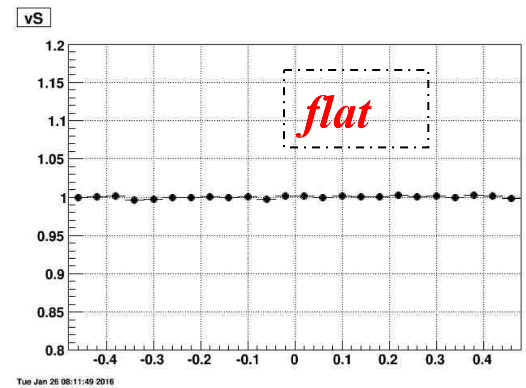
Cp



Cp_perp



Cp/Cp_perp



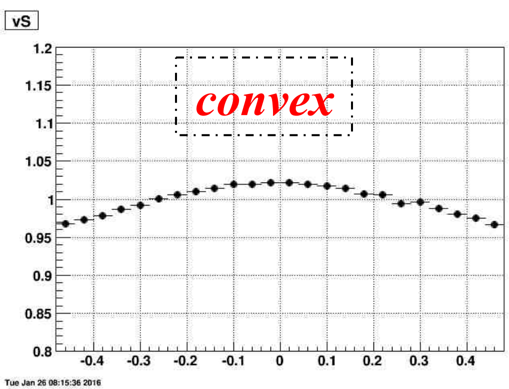
Cp, Cp_perp are flat

Since there is no charge dependence in the azimuthal distributions w.r.t the reaction plane,   in both cases the real and shuffled event distributions are similar

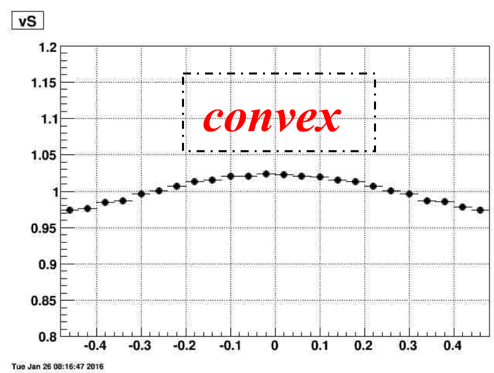
Shape response of correlators to physics (contd)

Simulation results with flow and decay but no charge asymmetry

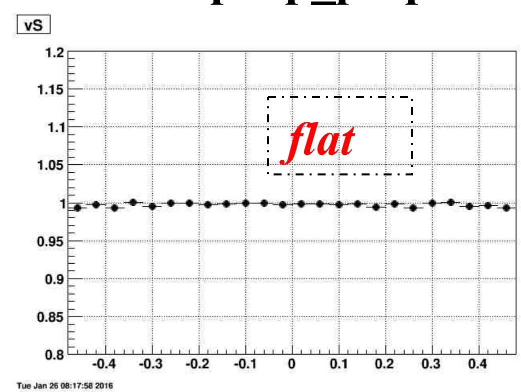
Cp



Cp_perp



Cp/Cp_perp



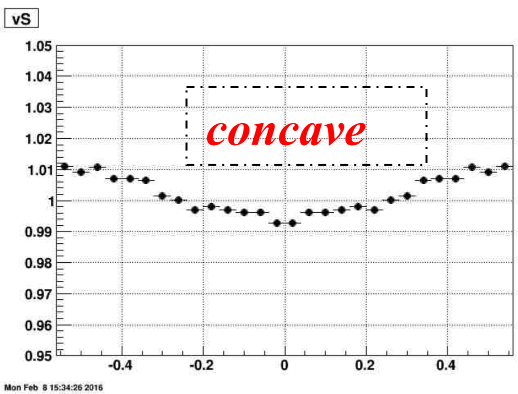
Cp and Cp_perp show convex response to flow + decay

Decays make the real event distribution narrower than the shuffled event distribution in both cases

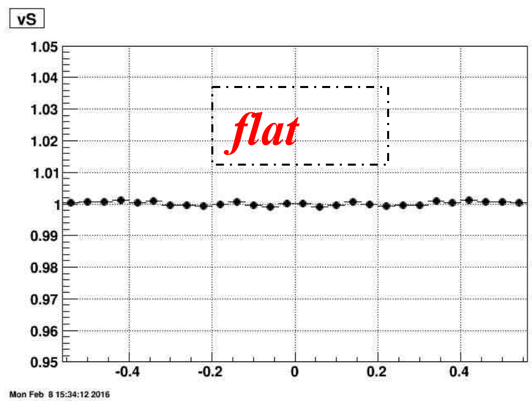
Shape response of correlators to physics (contd)

Simulation results with flow + charge asymmetry ($|a_1| > 0$) but no decay

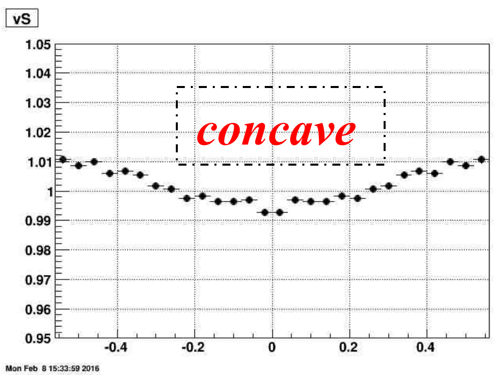
Cp



Cp_perp



Cp/Cp_perp



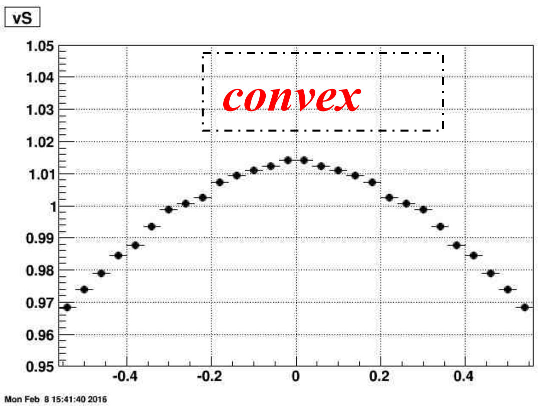
Cp is concave because both positive and negative charges make the real event distribution broader than the shuffled event distribution

Cp_perp is flat because of equal and opposite contributions from positive and negative charges

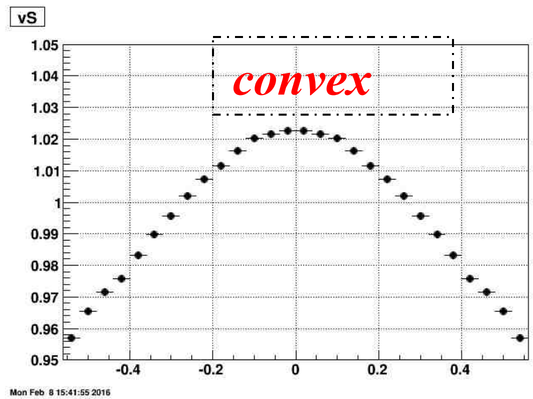
Shape response of correlators to physics (contd)

Simulation results with flow + charge asymmetry +decay

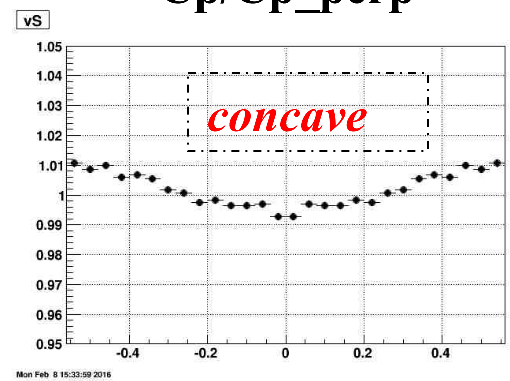
Cp



Cp_perp



Cp/Cp_perp

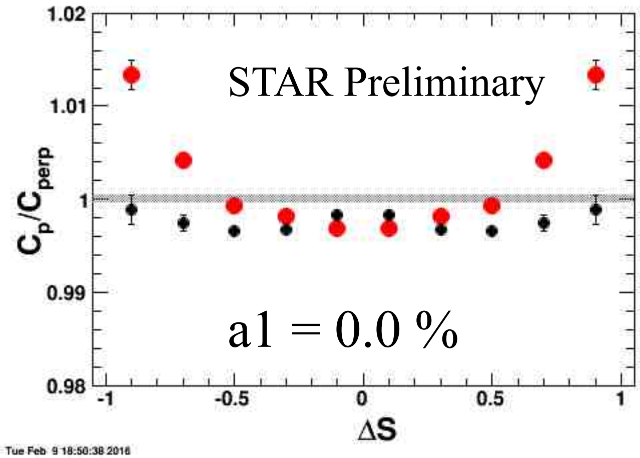


ΔS

Due to the charge asymmetry term Cp is broader than Cp_perp making Cp/Cp_perp concave

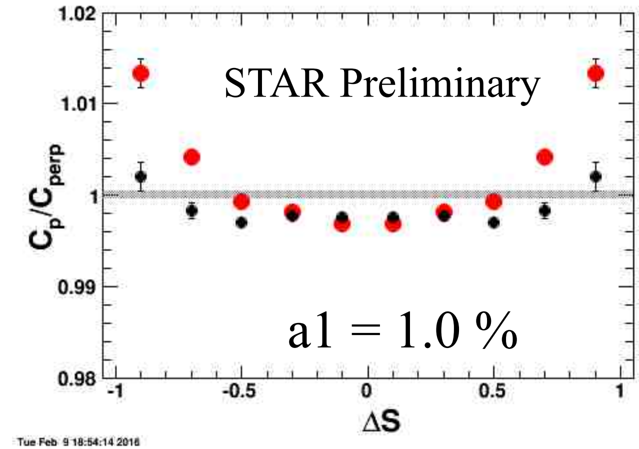
Next we dial the value of a1 to obtain a match with Cp/Cp_perp obtained in the data

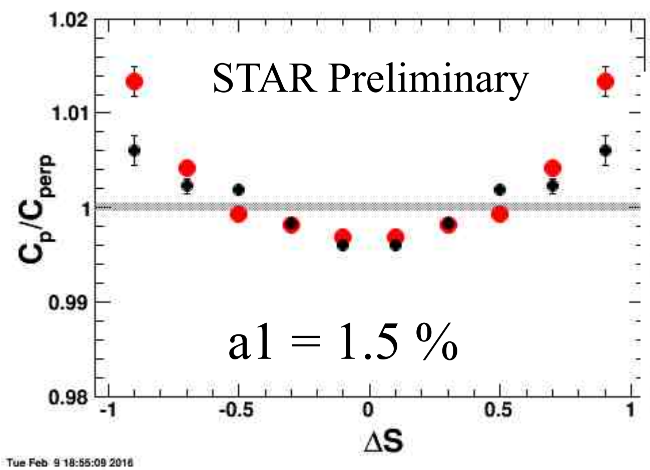
Cp/Cp_perp_sim for different values of a_1 compared to Cp/Cp_perp_data

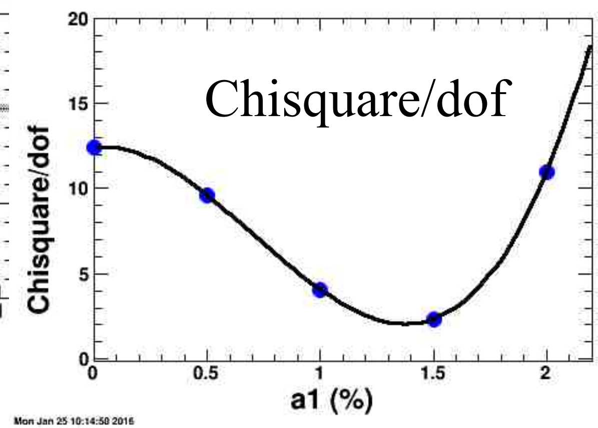


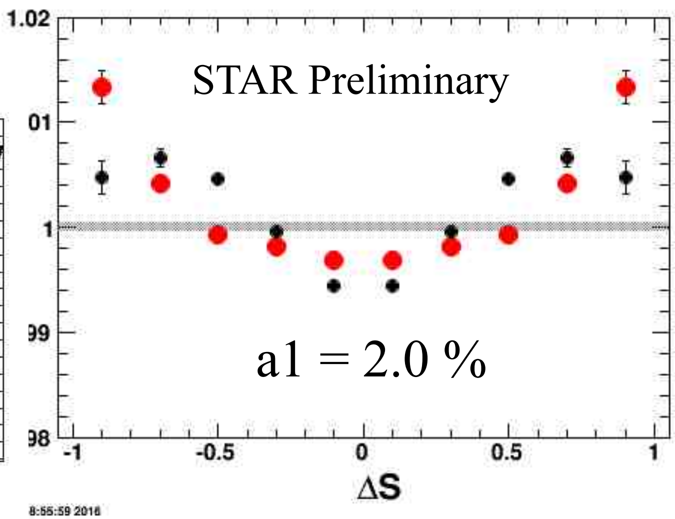
SIM :Black symbols

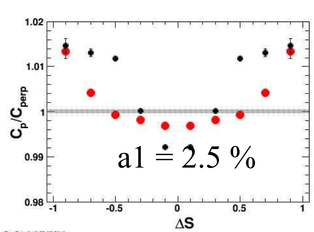
Data : Red Symbols





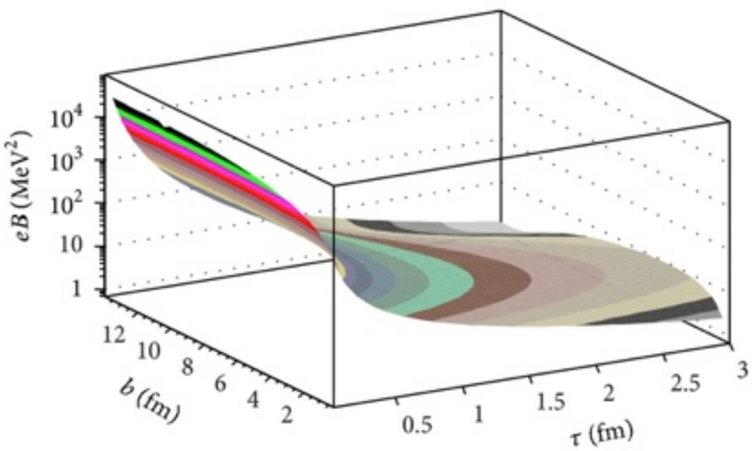






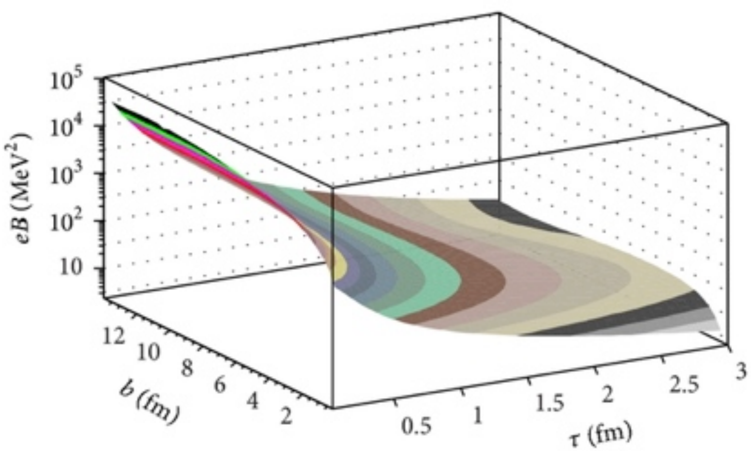
This analysis gives 1.0 < a_1 (%) < 1.5

Outlook



Au+Au 200 Gev

Y. Zhong et. Al.Advances in High Energy Physics Volume 2014 (2014), Article ID 193039



Au+Au 64 GeV

The magnetic field profile becomes somewhat stronger and lasts longer as the collision energy decreases.

The method is being applied to measure a_1 at 39 GeV

Summary

A multi-particle method has been applied to detect the charge asymmetry in 200 GeV Au+Au collisions.

All effects not connected to the parity violating signal a_1 are absent in Cp / Cp_perp. By comparing (Cp/Cp_perp) from sim with (Cp/Cp_perp) for data one obtains a measure of a_1

For <pt>=1.3 GeV/c in (30-50) % centrality in 200 GeV Au+Au collisions this method gives

$$1 < a_1(\%) < 1.5$$

STAR Preliminary Result